UNITED STATES UTILITY PATENT APPLICATION

for

MONITORING SYSTEM AND PROCESS FOR STRUCTURAL INSTABILITIES DUE TO ENVIRONMENTAL PROCESSES

by

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MONITORING SYSTEM AND PROCESS FOR STRUCTURAL
INSTABILITIES DUE TO ENVIRONMENTAL PROCESSES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Application Serial No. 60/200,114, entitled "Bridge Scour Monitoring System and Process" filed April 27, 2000, which application is being converted concurrently to a U.S. non-provisional application claiming the priority of U.S. Provisional Application Serial No. 60/131,127, entitled "Bridge Scour Monitoring Software" filed April 27, 1999. The above priority applications are hereby incorporated herein by reference in their entireties as are all of the references, including but not limited to any books, articles, reports, photos or published patent applications, cited throughout this application.

FIELD OF THE INVENTION

The present invention relates generally to bridge and other hydrological structure safety and, more particularly, to the collection, provision, and dissemination of data regarding specific bridges and other related structures via a computer system and real-time display. The methodology, system, and display of the invention allow users to make rapid and informed decisions about scour-critical bridges and other structures to ensure public and environmental safety.

BACKGROUND OF THE INVENTION

Bridges and other related hydrological structures have been known to fail unexpectedly. These structural failures result in inconvenience to travelers, expense to the public, destruction of property, and in the worst cases, even casualties. It would be beneficial to anticipate and forestall structural failures.

One particular cause of the failure of a hydrological structure is called a "scour." Scour occurs when hydrologic features, such as rivers, causeways, or lakes, are interrupted by bridge sub-structure elements. The process of scour may occur at any time but is exacerbated by flooding events and severe tidal

5   surges.

Conventionally, scour has three forms: local scour, contraction scour, and degradation scour. An example of local scour is the removal of sediment from around bridge piers or abutments. Interruption in the conveyance of water by a pier or abutment creates vortices at and around the interfaces of

10   these structure elements (see Figure 1.) These vortices create a turbulent state that results in the removal of sediment such that holes are formed adjacent to the pier or abutment: hereafter referred to as "scour holes." Contraction scour is the removal of sediment from the bottom and sides of a hydrologic channel. Contraction scour is caused by the increased velocity of water as the water

15   moves through a bridge opening that is narrower than the natural hydrologic channel. Degradation scour is the gradual removal of sediment from the channel bottom by the flow of the hydrologic feature. The sediment removal and resultant lowering of the channel bottom is a natural process, and, over time, large amounts of sediment may be removed. The erosion of soil

20   supporting a structure eventually leads to structural instability and ultimately failure if not corrected.

Thousands of structures span hydrologic features around the world, including in the United States. Even at the community level, it is difficult to maintain a diligent watch on all of these structures and inspections involving a person can be dangerous,

25   especially during flooding events. A number of scour monitoring devices are

described in Instrumentation for Measuring Scour at Bridge, Piers and Abutments. Transportation Research Board, 1997, NCHRP National Cooperative Highway Research Program, Report No. 396, ISSN 0077-5614, ISBN 0-309-06069-9, LC Cat Card No. 97-61382. However, scour problems can occur very suddenly and without

5   warning even with regular inspections and monitoring.

It is an object of the present invention, through the use of information technology, predict scour risk through constant data collection is needed in order to ensure safety for the public and the environments being protected by these structures and to efficiently gather, evaluate, and present data in a coordinated manner to allow

10   users to more effectively evaluate, prioritize, and determine the appropriate actions required to maintain public safety and preserve of public and private property.

SUMMARY OF THE INVENTION

A combination software system and methodology can be employed by a

15   person to effectively and safely manage bridges and other hydrologic structures. This combination requires upgrading the nature, quantity, and quality of the relevant data collected from bridges or related structures. Real-time data can be rapidly collected, processed, and logically presented with the prior and historical data, so that a response may be orchestrated in a timely and cost-effective manner. Corrective measures may

20   include physical inspection, closing of bridges to traffic, and/or repair or replacement of the structures in question.

Data collection, presentation, and timely user notification of problems are particularly important for successful monitoring of scour critical structures and other structures whose performance can be affected by meteorological and

25   hydrological conditions.

The above objects are addressed by a system and method with the means of extracting and processing real-time data from bridges and related structures and the local environment. The data are collected and relayed via a communications network to a central site. The historical and analytical

5   information concerning the structures are stored in a database and presented at the central site in a coordinated manner with the real-time data. Thresholds are established in any relevant parameter and when any such threshold is reached, the system presents a prioritized notice at the central site and notifies appropriate users of the system via relevant communication hardware such as,

10   phones, cell phones, facsimiles, pagers, PDAs (personal digital assistants) and instant messaging. The central site or database can provide a visual interface that allows a user to view the location, surrounding hydrologic features and any other structures within the local population density. The location view can include maps of the area that are interactive with users so that the order and

15   detail of the maps can be altered by the user.

       The system is connected to a communications network that may be the Internet, a local network with a portal to the Internet, or groups of networks and redundant computer systems and/or networks. The system of the present invention can include interactive pages and software code that routinely

20   interrogates data repositories, databases, Web sites, and other electronic media for collection of relevant data. Such interrogation may be programmed to run on a time or event basis, or some other such criterion as is known in the art and defined by a user, a system administrator or a default preference.

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BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A-1C depict one method of scour at a cylindrical pier;

Figure 2 is an elevation drawing of a bridge spanning a hydrologic

feature;

5 Figure 3 is a diagram of an embodiment of the system;

Figure 4 is a block diagram of the data collection of an embodiment a

the system of the invention;

Figure 5 is a block diagram of data notification and presentation in an

embodiment of the invention;

10 Figure 6 is a schematic depiction of a Sonic Fathometer scour-

measuring device;

Figures 7-10 are embodiments of a data interface of the invention

providing map presentation screens indicating that a threshold is triggered for a

bridge structure with additional screens providing more detailed information,

15 maps, and historical information; and

Figure 11 shows an embodiment of the architecture of a communication

and retrieval application for data monitored by the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

20 The above objects are addressed by a system and method with the

means for the collection, compilation, presentation, and communication of

structural and other environmental data. Environmental data includes, but is

not limited to, meteorological data, hydrological data, and geological data.

Figure 1A shows scour 103 around a cylinder 101 from a prospective

25 view with surface wake 102, caused by turbulence.

Figure 1B shows a top view with a wake vortex.

Figure 1C shows a side view with a wake and horseshoe vortex.

Figure 2 is an elevation drawing of a structure, in this case a two-span

bridge, spanning a hydrologic feature. The bridge 200 has one pier 201 in the

5   center and two abutments, 202 supported by friction piles 203. Water 204

flows under the bridge opening creating scour holes 205 in front of and around

the pier 201 and abutments 202.

Figure 3 is a diagram of an embodiment of the inventive system and

representative of a central system computer, distributed computer system, or

10   the like where the database resides. There are means for connecting to

communications networks locally and remotely, such as through the Internet.

Such means include a wired or wireless data communication between

components of the member. See Computer Networks 2d Ed., by Andrew S.

Tannenbaum, Practice Hall (1996) for a description of Network

15   communications that may be employed in the present invention. The system

may interact with other systems and servers to send and receive data, such as

relevant governmental (state and federal) agencies and third party weather

information services.

In Figure 3, "Historical Archive" 300 represents the database of

20   information related to structure event performance data. Included in this

information is the historical data for each structure including prior events and

the time frame of these events. "GIS" 301 represents a Geographical

Information System; this is data of any and all types that is put into a visual

form. One or more types of data can be displayed to provide the user with the

25   benefit of visual interpretation of data and relationships between various data

sets. For example, the user may want to create a map to depict the relationship of rivers, roads, bridges, dams and river gauges to review the coverage of a gauge network.

The "Structure Information Database (SID)"302 contains the structural-

5   related data: possibly including, but not limited to or required to have, structural detail, attributes, plans, inspection reports, maintenance memos, and bridge history. Also see figures 8 and 10 showing the "Structure Detail" and "Report of Event". The historical data may contain original specifications of a structure itself, inspection reports, as well as the occurrence and type of events

10   involving the structure. Thresholds are determined by studying factors including but not limited to, known parameters of the structure, current and expected environmental conditions, human populations and possible damage costs. These thresholds are established, in an embodiment, for virtually any condition requiring intervention. In a preferred embodiment, the method of

15   user notification as well as the method for determining which user or users require notification can be established based upon the type and extent of threshold being exceeded and the threshold prioritization.

Referring to Figure 3, relevant data is routinely collected via features in the software program 303, which can be accomplished using an automated

20   software program called a "bot" or "Web-robot," and the data is stored into the appropriate database for retrieval. This data can include hydrological 304 and meteorological 305, and may be, data from sites such as, The National Oceanic and Atmospheric Administration (NOAA), the National Weather Service (NWS), the U.S. Geological Survey (USGS), radar sources, as well as data

25   from physical sensors and other such monitoring devices. Such devices 306

may include river gauges that measure depth and flow rates, sliding collars, and other such devices that may directly measure structural parameters on a structure, like strain gauges, deflection meters, current traffic, and even relevant parameters regarding the local environs or device parameters like

5   battery level or a malfunction or calibration indicator. Such devices may be battery powered or directly connected to power sources so that real-time data may be remotely monitored via a communication network such as the Internet. Other data may be collected from such devices by hand or by human measurements and input into the system. The above and other data may be

10   used to identify conditions that may result in severe flooding or other water-related catastrophic events.

The software program, 303 of Figure 3, can run the entirety of the system and may include known software, including operating systems and languages. This software, may be distributed and operate via known

15   communications channels. For example, Windows NT, Windows 98, Mac, Unix, Linax, BSD and many other such operating systems are known in the art. Java, HTML, PERL, C++ and other such languages may be used with the appropriate compilers, assemblers, and servers. Mapping data is presented using a Geographical Information System (GIS) 301 software such as ArcInfo,

20   ArcView, Geomedia, or any other GIS software product. Such known programs and languages may be used in building a system of the invention. In a like manner, the system hardware can include computers, communications, local networks, modems and memory and may be assembled and built from known sources including suppliers such as IBM, Dell, Apple, Hewlett-Packard,

25   EMC and Compaq.

The operation of the system, in an embodiment, will analyze the data from at least one source and observations utilizing algorithms and comparing the results against thresholds, that when exceeded can cause an alert 307 to be output to a user and/or to another systems. Such thresholds may be arranged

5   into priority levels and alarms. For example, numerical thresholds for scour, flooding or some other such criterion are resident in the system and implemented as determined by the user or a system administrator. In certain embodiments, non-numerical codes may be used. Referring to Figure 3, the software 303 outputs automatic alerts 307 to users 309 when thresholds are

10   exceeded. Such alerts may be transmitted via 308 telephone, cell phone, pager, e-mail, instant messaging PDA (personal digital assistant) or equivalent means to inform those knowledgeable people capable of technically evaluating and responding to critical issues needing immediate attention. The user 309 can log onto the system to remotely review the information and data via an application

15   interface 310. In a preferred embodiment, the data is presented as shown in Figures 7-11. The user is preferably a person that has the background, training and understanding to respond to the wide variety of circumstances that may occur. A security measure such as a password, call back verification, biomatrix authentication, or voice or finger print identification can be included in the

20   system to allow only permitted users to enter the system and review the data. Likewise, data can be encrypted during transmission such as with a virtual private network to prevent unauthorized interception of the data.

In one embodiment, the inventive system provides the Department of Transportation (DOT) engineers the ability to monitor a bridge population for

25   potential scour events with real-time hydrologic and meteorological

information. In a preferred embodiment and as described above, the system uses a web browser capable of encoding and decoding encrypted data from Active Server Pages (ASP's) and software programs that allow interrogation by the system. The Internet is a preferred communications network because it is

5   widely available on a number of platforms , and the system can be organized by and for a governmental agency responsible for monitoring hydrological structure integrity. The system can run on local server which may be operated redundantly to decrease the likelihood of information being available. One central server may be enabled to access other individual servers in other

10   locations including those with security systems in place.

In another embodiment, the system can be used to prioritize risk factors and to calculate probabilities of failure to create a prioritized watch list of structures. For example, this would allow a user to increase the effectiveness of emerging presume and repair response to better use limited resources.

15   The system can collect and evaluate data and relevant information from the various sources listed above and, along with the monitored real-time data from the Web-robots, identify flooding or other weather related catastrophic possibilities. Such possibilities can be automatically reported to the proper user or users.

20   The inventive system can also provide a list of scour critical structures that may be affected by a critical event. The system could alert a user via a communication means such as a cellular phone, pager, fax, e-mail or instant messaging that the user should monitor the critical event. In some instances, structural safety inspectors or other relevant personnel (such as emergency

25   response, police or fire fighters) can be notified when catastrophic events

require closing of structures or other such extreme actions. As described above real-time and historical data, structure construction information and structure experience data can be made available to the monitoring personnel through in interface.

5   Databases can be separate, however, in alternate embodiments of the invention, the data could be stored in a single database or in other configurations and combinations of databases. A database preferably resides in a secure computer system that is routinely monitored, optimized, and backed-up to ensure data safety quality and preservation. In a preferred embodiment a

10   database server provides data to a web browser via encryption. The encryption may be of the public/private key type, private key only type, or other such encryption means and key bit widths that are known in the art. The system is connected to a communications network that may be the Internet or a local network with a portal to the Internet, groups of networks and redundant

15   computer systems and/or networks, or a dial-up network via telephone lines, as known in the art.

      Figure 4 is a block diagram of an embodiment of a data collection methodology of the invention. Data can be collected from a plurality of sources and can be stored in a central database to ensure continuing availability

20   even if the source data charges. The central database can be an object oriented database management system. Suitable databases include a structured query language compatible database, an Access database, an Oracle database, a mainframe database, a tab delimited database, a Comma-Separated Value database or an Excel database. Threshold values can be defined by the user

and could vary according to each user's preferences guidelines and processes.

Threshold values for the meteorological data 400 might be as follows:

Radar 401- Decibels of reflectivity indicative of storm intensity or

predicted inches of rainfall over a measured period of time like 24 hours. (See

5   Table 1)

dBZ	Rainrate (in/hr)
65	16+
60	8.00
55	4.00
52	2.50
47	1.25
41	0.50
36	0.25
30	0.10
20	Trace

Table 1: Rain Rate in decibels and inches per hour

Tide data 402- A particular tidal stage measured in feet above sea level,

e.g.; 5.0 ft.

15   Snow 403- Depth of snow cover measured as an average over a

particular watershed.

Warnings 404- The National Weather Service (NWS) utilizes codes to

indicate specific types of warnings. Notification may need to be sent when a user

specific warning is of concern, for example:

20

"FLWALB
NYZ042-170300-

FLOOD WARNING
25   NATIONAL WEATHER SERVICE ALBANY NY
815 AM EDT MON APR 16 2001"

The above is an actual heading for a Flood Warning issued by the NWS office in Albany, NY. These warning types could, themselves, be reason for notification and considered a threshold for system activity.

Threshold values for the hydrological or geological data 405 might be

5   as follows:

River 406- River Flow measured in cubic feet per second (cfs), River Stage measured in elevation, and Ice determined by whether or not it exists

Soil Parameters 407- Soil types/soil wetness indices

Vegetation 408- Vegetation type and density of population

10   Seismic 409- These threshold values (would be in a measurement of the Richter scale). (See Table 2).

	Mercalli	Richter
Mild	I-III	0-4.3
Moderate	IV-V	4.3-4.8
Intermediate	VI-VII	4.8-6.2
Severe	VIII-X	6.2-7.3
Catastrophic	XI-XII	7.3-8.9

Table 2. Seismic measurements severity scales

The Device 410(direct scour measuring type) threshold values will be

15   determined by comparing the elevation of the bottom of foundation with the elevation of the structure being monitored. This value could be one or two feet (or other distance units) above the bottom of structure footing as measured in an elevation datum. In other embodiments the value is in the range of 0.25 feet to 10 feet or more. There are over a dozen direct scour measuring devices that

20   are employed to monitor structures. Most common are the magnetic sliding collar 411 and the sonic fathometer 412(see Figure 6, element 602.). These devices are employed to determine scour activity when connected to a system of telemetry. A sliding collar is a stainless collar with large magnets attached.

The collar is clasped loosely around a pipe driven in front of a substructure element. Inside the pipe are small switches that are activated by the magnets on the collar as the collar slides downward during the progression of scour at the substructure element being monitored. The sonic fathometer, 412 and 602

5   is simply a transducer 602 mounted on a structure 601 that sends sonic impulses 602 around a substructure element and records depth readings. These devices can measure a scour hole 605 as it is created.

Figure 5 is a block diagram of the user notification and presentation portion of the system according to principles of the invention. The following

10   are definitions for the Structure Information Database (SID) 500 portion of the system:

Structure Type- The facility that supports traffic over or from hydrologic features. Examples include, but not limited to, bridges, dams, levees and culverts.

Foundation- The supporting element of a structure, including but not limited to

15   a footing, pilings, gabions, soil.

Traffic Volume- This is typically measured in vehicles per day or Average Daily Traffic (ADT).

Detour Length- The next best route of travel if a structure needs to be closed to traffic. This would be measured in units of distance, e.g., miles or kilometers.

20   Critical Flow- This is the volume of water passing under a structure that is critical for the crossing structure. This can be measured in cubic feet per second.

Critical WSE- This is the Water Surface Elevation, which can be measured in feet, that is important for the structure being monitored.

Critical Rain- The intensity of rainfall measured in inches or another unit over

25   a 24-hour period.

Low Chord Elevation- The elevation, measured in feet, of the lowest

structural element spanning a hydrological feature.

Feature Carried- Example features include, but not limited to, a highway,

railway, pedestrian walkway, building, or wharf.

5   Feature Crossed- The hydrological feature the structure crosses, including but

not limited to a river, stream, lake, canal or causeway.

Pictures or Audio- Digital images, still or video and with or without audio, or

audio alone of the structure and local environment.

In a preferred embodiment, a user 501 may be notified by pager, cell

10   phone, or facsimile of a scour-critical event and subsequently log on to the

Internet and the inventive system interface 503 using the proper security

passwords and any other such codes. The user can receive a detailed visual

notice of the event and the threshold being exceeded. The user will be

presented with a map of the area, for example, of Rhode Island (R.I.) as shown

15   in Figure 7. The left map of R.I. is divided into six quadrants as shown in

Figures 7-10. These divisions are determined by watershed boundaries or

weather zones an embodiment of the invention.

Figure 6 shows an embodiment of a scour meter, in particular a sonic

fathometer 602, mounted on a pier substructure element 601. Sonic waves 603

20   reflect off the channel bottom 604 to indicate to the fathometer the size and

depth of the scour hole 605. Such depth can be used to indicate the potential of

exposing the bottom of the footing 606 to the scour hole 605.

Referring to Figures 7-10, appearing in the top middle of the display is

an event legend 701 that shows events that typically occur every 10, 50, 100, or

25   500 years onto the map. A watch list 702 can be created from the structural

information database of bridges located in the quadrants. Scour Critical

bridges can be displayed as dots 703. The user can focus on a manageable

group of structures as shown 704. The scour-critical structures in this quadrant

can be marked by Bridge Numbers or structure numbers. The user can see the

5   current precipitation via radar 705 in the affected area with the mouse/cursor.

In this preferred embodiment, an overlay presents the precipitation data.

The user can view the meteorological information and the affected

structures sorted against the watch list. The user can sort the list 706 by

structure type, structure function (including railroad or roadway) and determine

10   which structures are most critical. In this embodiment these operations can be

selected by pointing and clicking with the mouse at a terminal or by another

input device inducing a touch screen, a keyboard, a track pad or stick

controller. By selecting on the bridge number or location on a map the user is

provided with the structure specific information (see figure 8), with data

15   concerning the structure 800(possibly including, but not limited to, structure

type, length, breadth, function, year built, number and type of gauges attached,

prior events, structure plans, digital images (still or video) including a map 801.

The structure can be identified and alternate routes can be highlighted. A

"View Gauge" button 802 can be provided for viewing actual gauge data (see

20   Figure 9).

Figure 9 is a graphical image of an actual river gauge 900 with real-

time reporting. The user is provided a "View Report" button 901 for viewing a

report of the event or past events (see Figure 10).

Referring to Figures 7-10 a "Toggle Radar" function allows the user to

25   obtain the radar weather. A "Search for Bridge" function allows the user to

select a bridge and find its location on the map. A "Sort List" function allows

the user, as mentioned above, to sort any particular structure against the "watch

list." A "Bridge History" function allows the user to access the historical data

regarding the bridge as described above. Also, as described above, the user can

5   view the real-time gauge data and compare that data to the expected readings.

A 50-year Precipitation event for a particular structure and relevant structure

data is listed. From the inventive system the user can report and recommend an

action plan. Actions can be prioritized and might include physical inspection of

the structure, closure of sections of the structure and/or re-routing of traffic.

10   The user can edit and then submit his report by clicking, as known in the art.

The report form presented to the user by the system may have boxes to be

checked for channeling the information to the proper authorities. The report

will be a record and a means for communication for inspectors, engineers, and

management. The report may be accessible from several locations in real-time

15   for timely decisions and actions to be taken.

Figure 11 depicts an embodiment of a data communication network of

the present invention with multiple data sources communicating in a network to

a database and, in real-time, to a user interface. The system can utilize the

Internet as its communication network and in object oriented database

20   management system (OODBMS) for rapid customized development and

improved system integrity. Preferably the system uses a multitier system

architecture for improved flexibility and scalability.

A "Profile" in accordance with the invention can be an assembly of attributes

established for each user whereby the system responds specifically to the attributes in

25   the profile. Profiles can define the behavior of the user interface. Each profile can

contain what real-time data sources can be interrogated for the profile, the explicit

conditions that cause a notification to occur, and the precise form the notification

takes. In a simple example, a profile could correspond with a user and the user's

requirements for data monitoring. However, more complicated setups are certainly

5   possible, where the user is a large organization, there may be a profile to notify

separate departments of particular occurrences, as well as, key individuals within the

group.

As a simple illustrative example, if a user wishes to be notified when the

National Weather Service (NWS) issues a flood warning for a particular river,

10   watershed or county of a particular state. He may wish to be faxed the text of the

message. If the warning is issued during business hours, he may wish to be paged

with a short text summary of the warning. He might also wish to be able to access the

system and view a log of everything that the monitoring systme has sent to him.

Interrogation. The profile can be configured to interrogate the NWS website

15   listing weather warnings for that state as well as the specifics including county,

watershed, river and current time.

Conditions. There are two sets of conditions for this example profile: (a) a

warning from the state's NWS warning site must be a flood warning, and it must

affect the particular county, watershed, river and (b) a warning from the state's NWS

20   warning site must be a flood warning, it must affect the particular county, watershed,

river during business hours.

Form of notification. If condition (a) is satisfied, a fax with the text is sent to

a fax number defined in the user's profile. If condition (b) is satisfied, a summary is

generated and sent to his text pager/cell phone. If either conditions (a) or (b) is

25   satisfied, a log of defined form is updated in the database. There are certainly many

20/454093.3   -18-

more complicated profiles or combinations of profiles that can be customized to the user's needs.

In particular, as this pertains to monitoring scour, a use could include an interrogation of gauges, where if the gauge reports a value that is greater than a

5   predetermined threshold, or multiple gauges combined are report a set or combination of values greater than an established threshold, a map is generated with the locations of the bridges/dams associated with the offending gauges, as well as a an ordered list of which is likely to be most critical based on the Structure Information Database (SID) data. This map can be both faxed to a particular office and displayed on the

10   user's interface.

The profiles, as well as logs, commonly used sets of conditions or means of generating forms of notification, may all be stored in a database. The system may derive some reliability from the programs used in its implementation (ie. it may get recoverability from a transactional database) but there will likely be a form of self-

15   monitoring going on, where a second monitoring system may be running, and one of its profiles is interrogating the first, and if the first fails, the second will attempt to restart it, while notifying a technical support person that the program malfunctioned and may or may not require review.

It is to be understood that the above-described embodiments are simply

20   illustrative of the principles of the invention. Various and other modifications and changes may be made by those skilled in the art; which will embody the principles of the invention and fall within the spirit and scope thereof.